RDT

Brief

Research Investigation 98-006 **January, 2005**

Advanced Research of an Image Analysis System for Hardened Concrete

A National Pooled Fund Effort

Introduction

Determination of the air-void system in hardened concrete has been relied upon for years to evaluate its resistance to freezing and thawing. Of more significance than total volume of air, the air-void system characteristics, such as specific surface, spacing factor, and void frequency, provide valuable information for assessing concrete durability and long-term performance. The accepted means of determining these characteristics in hardened concrete is ASTM C457, Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete using either Procedure A, the linear-traverse method, or Procedure B, the modifi [illegible] ount method.

For years, ASTM C457 has involved a human operator participating behind a microscope distinguishing among the various concrete constituents (air, paste, aggregate) observable on the surface of a prepared concrete specimen. This process has been long recognized as tedious, time-consuming and, for the most reliable results, requiring a skilled and experienced operator. Besides human operator subjectivity, other factors such as variations in specimen surface preparation, difference in equipment set-up among laboratories, and the inherent statistical variability existing in the test method itself each raise concerns regarding the general variability of ASTM C457 results. However, many continue to depend upon ASTM C457 using a human operator for evaluating the air-void system in hardened concrete and often follow with making decisions, which may have significant physical and financial impact both short and long term. Thus, the development of an automated, air-void analysis system, which would produce reliable ASTM C457 results, minimize variability, and save time and effort, would serve as a significant advancement for those responsible for and relying on the test method.

Development of the ACE System Prototype

In 1998 the Missouri Department of Transportation (MoDOT) initiated work with the National Nuclear Security Administration-Kansas City Plant (NNSA-KCP), a government contractor for the U.S. Department of Energy, to develop a fully automated system capable of reliably analyzing hardened concrete in accordance with ASTM C457 using the linear traverse method. At that time, the NNSA-KCP had established extensive capabilities through years of experience in video imaging technology, including successfully integrating data/image acquisition, signal processing, feature extraction, and pattern recognition techniques into user friendly, automated analysis environments. The NNSA-KCP applied this same technology using integrated scanning and video imaging to

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pursue the development of an automated system intended to produce ASTM C457 linear traverse results to a greater degree of accuracy, reliability, and repeatability than current conventional means (human-operator approach).

Initial work with the NNSA-KCP to develop a prototype system using image analysis techniques proved to be productive. Specifically designed to analyze a sample of hardened concrete in accordance with ASTM C457's linear traverse method, the prototype system included both hardware components for image acquisition and customized software for baseline image processing and pattern recognition. ASTM C457 linear traverse results determined with the prototype system, referred to as the ACE system (automated concrete evaluation system), were found to be in general agreement with results obtained by a human operator.

Pooled Fund Study Initiative: "Next Generation" ACE System

The potential of the prototype system then prompted MoDOT in 2002 to take the lead on a national pooled fund effort with several other states to further advance and complete the development of the ACE system with the NNSA-KCP. In addition to funds contributed by Missouri and NNSA-KCP, twelve states have contributed and participated in the pooled fund effort. These states include Arkansas, California, Colorado, Illinois, Indiana, Iowa, Minnesota, Montana, Nebraska, Ohio, Virginia, and Wisconsin. The initiative of the pooled fund study not only helped secure the project financially but also provided an opportunity to draw on the experience and knowledge of others highly familiar with the ASTM C457 test method. In addition, it enabled a much broader range of concrete samples (e.g. various aggregate types, paste characteristics, air-void systems) upon which the ACE system could be improved and validated.

Since the initiation of the pooled fund study, the NNSA-KCP has continued to make image processing software enhancements and has also upgraded the hardware components into a "next generation" version of the ACE system. While very similar to the original prototype, the recently completed "next generation" ACE system uses a high precision two-dimensional computer-controlled stage (sample platform) to move the concrete specimen under an industrial grade inspection microscope. The image acquisition system consists of fire-wire color CCD camera, a frame grabber for image capture, and a 2.8 GHz processor PC. Improvements continue to the customized image processing software used to identify air voids as small as 5 microns and to extract concrete component characteristics used to calculate the concrete microscopical properties of interest in accordance with ASTM C457. All system components are linked via a graphical user interface, which aids the operator in the image acquisition, analysis, and review processes. The current ACE system is shown in Figure 1 with Figure 2 providing a screen shot from the system analysis graphical user interface. For a single specimen, image acquisition for the ACE system currently takes approximately 3 to 4 hours, while system analysis requires approximately 3 hours; however, all with little to no human operator intervention.

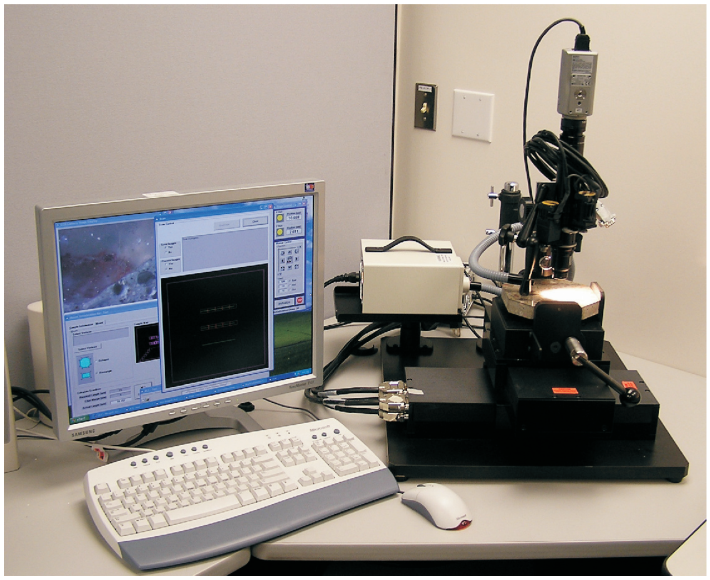

Figure 1 "Next generation" ACE system (automated concrete evaluation system) to determine the air-void system characteristics in hardened concrete, developed by the NNSA-KCP.

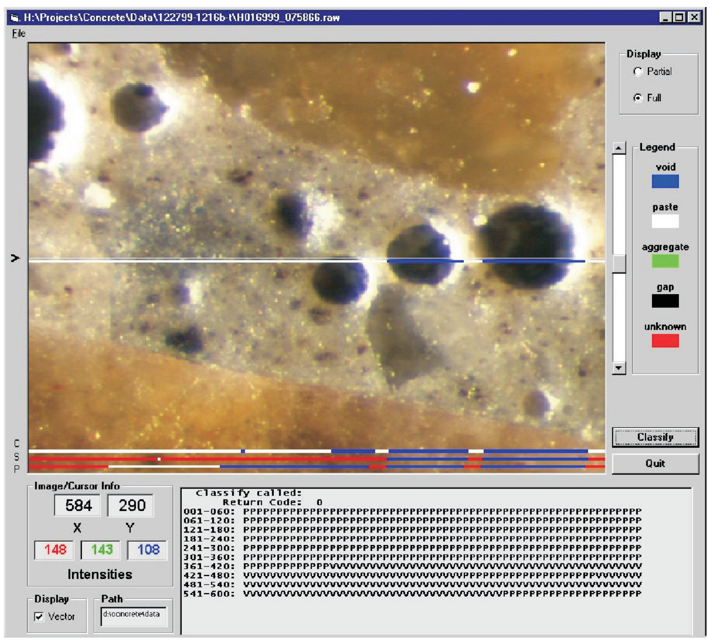

Figure 2 Sample screen from the ACE system data analysis graphical user interface.

Concrete specimens analyzed using the ACE system are also surface prepared as specified in ASTM C457, under Sampling and Section Preparation. Due to its two-dimensional, microscopic image scanning process, though, the ACE system is more sensitive to sample surface condition. Thus, appropriate procedures should be carried out to ensure a flat, level surface for most confident scanning and data imagery collection.

Variability of ASTM C457: Round Robin Testing Program

As part of the effort to achieve successful development of the ACE system, with improved accuracy and minimized variability, an evaluation of the variabilities associated with ASTM C457 using a human operator was determined necessary by the pooled fund study participants. A two-phase round robin testing program, concurrent with the pooled-fund study, was initiated among nine laboratories (ten in phase 2) to estimate the variability in a human-operator, ASTM C457 linear traverse. The baseline variabilities obtained in the study would then be used as a benchmark for the ACE system. The round robin was set up in two phases, each using the same five concrete specimens which were obtained from different locations around the country. In each phase, the participating labs performed a total of nine linear traverse tests – one linear traverse on four of the specimens, and five linear traverses, using five different sets of traverse lines, on the fifth specimen. All tests were to be run at 100X magnification on the participating lab's equipment. For phase 1, the concrete specimens were prepared by the lab supplying the specimen, using the lab's standard equipment and procedure. For phase 2, the five concrete specimens were collected and the surfaces were prepared again but by one lab.

The sources of variability associated with the linear traverse include
(1) specimen preparation effects
(2) operator experience and ability
(3) equipment (magnification, method of viewing, lighting)
(4) inherent statistical variability of the linear traverse

The effects of sample preparation were assessed by comparing the results of phase 1 and phase 2. The results of the different laboratories for each specimen were used to estimate multilaboratory (between-lab) variability, which represents the effects of operator ability and equipment, along with the inherent statistical variability of the linear traverse. Equipment effects due to magnification were eliminated by requiring all labs to test at 100X; however, effects of different methods of viewing (directly through the microscope, or indirectly using a monitor and video camera attached to the microscope) and lighting could still be present. The five repeated traverses of one sample (RR2) were used to estimate single operator variability (within-laboratory variability), which represents the inherent statistical variability in the test method. The ASTM C457 air void parameters were calculated for each set of data.

Figures 3 and 4 summarize the air content and spacing factor results from the sample which was traversed five times. These results give a picture of both single operator and multilaboratory variability. The open symbols represent the five different traverses performed on the specimen.

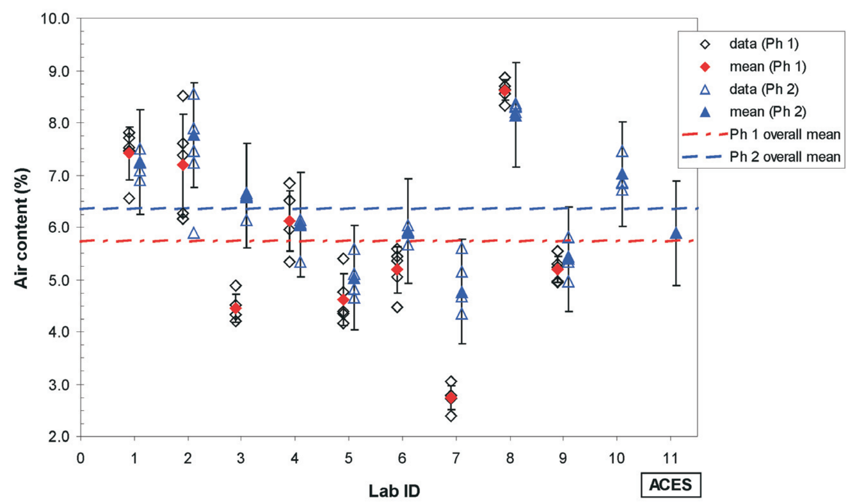

Figure 3 RR2: Variation in air content -- all laboratories

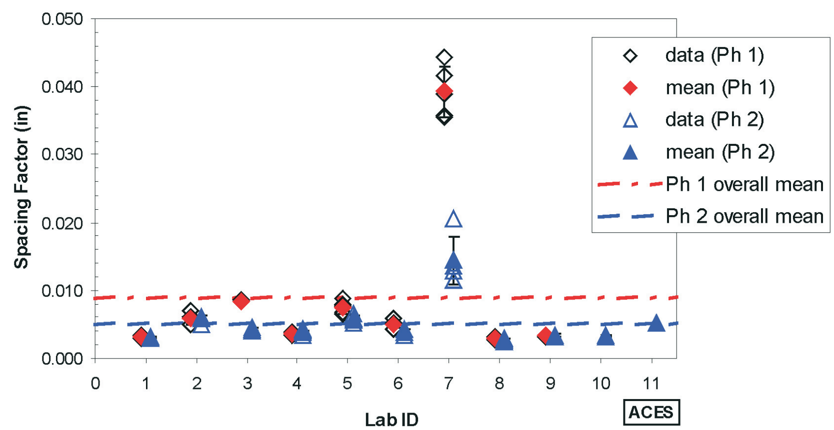

Figure 4 RR2: Variation in spacing factor -- all laboratories

The filled symbols represent the mean of these five traverses. The dashed lines represent the overall multilaboratory means for the specimen. As the figures shows, when results of all laboratories are considered, there is substantial variation in both air content (Figure 3) and spacing factor (Figure 4). Lab 7 in particular had substantially different results for spacing factor, which skewed the data considerably. The round robin testing data also indicates that precision and accuracy do not necessarily go hand in hand.

The five round robin specimens were also analyzed by the original ACE system, since at the time the next generation system was not yet complete. The results for RR2 (single scan) of the ACE system are shown as Lab 11 in Figures 3 and 4. Despite the data was determined using the original prototype, the results have been found to be within range and compare quite well among the other laboratories. A complete analysis of the round robin results will be available in an upcoming report to be published by MoDOT.

Anticipated Results and ACE System Completion

The results of the round robin testing program indicate that considerable variation exists in a human-operator linear traverse and that a reliable, automated means of conducting ASTM C457, which would minimize the variability, is greatly needed to provide the utmost confidence in linear traverse test results. In addition, incorporation of the automated system data demonstrates that the ACE system has great potential for serving as a reliable, automated means of providing ASTM C457 linear traverse results.

Work with the pooled fund study and the NNSA-KCP is anticipated to complete in early 2005. While results from the original ACE system prototype have been promising, the upgraded "next generation" ACE system along with further enhancements to the image processing software should successful result in an automated, user-friendly system capable of providing ASTM C457 linear traverse results in an efficient and reliable manner. This would be a welcomed improvement and have a significant impact on those responsible for concrete testing and research.

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